LADD – LASER ASSISTED DEEP DRAWING

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Abstract

In the current work, cup drawing experiments with laser assistance are presented where only selected areas of the work piece have been heated up. Since the strongest deformations occur at the outer circumference of the blank, only that area has been heated up by a defocused laser beam. Selective laser heating of the work pieces was performed by diode as well as Nd:YAG laser radiation. The forming load for the experiments was established by a small hydraulic press with a maximum drawing force of 630kN and a hydraulic die cushion. During the experiments, the drawing path and all relevant forces have been recorded.
Experimental results clearly demonstrate that this combined laser forming process is enlarging the possibilities of conventional deep drawing.

Keywords: deep drawing, hot forming, laser assisted deep drawing

1 Introduction

In production engineering 3-D parts can be produced by different forming methods. For example, deep drawing is a well established process in automotive industry. Fig. 1 shows schematically the setup of a simple cupping test. This process transforms a mainly flat sheet blank into a hollow 3-D part by pressing it into a die. High true strain results from strong plastic deformations which can only be achieved by strong forces applied to the work piece. In some cases limitations arise from the mechanical properties of the used materials since the material cannot withstand the needed forces. Flow curves (e.g. **Fig. 2**) of different materials show that plastic deformations can be facilitated by higher temperatures.

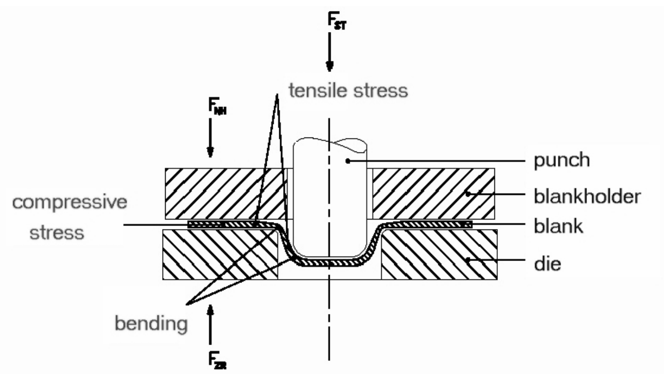

Fig. 1: *deep drawing: cupping test*

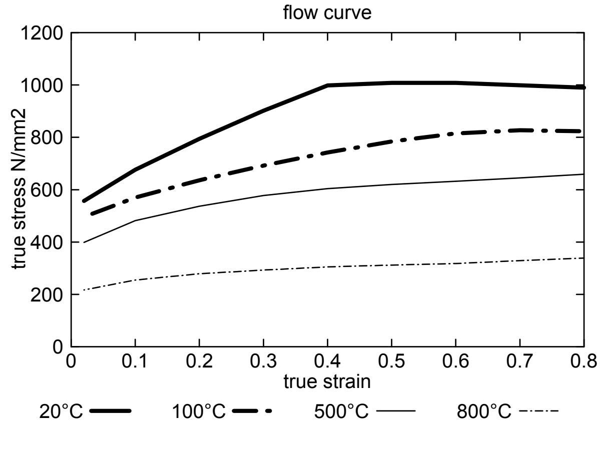

***Fig. 2:** flow curve: X5CrNi1810 [1]*

Nevertheless, an overall heating of the work piece has serious disadvantages, like unwanted surface modifications or handling problems. On the other hand a localized heat input changes the material properties only locally while the remaining part of the material is unchanged. Additionally, this gives the possibility to influence the local flow characteristics of the material .

The usual way to solve problems with deep drawing is to use multi step drawing. In this case the drawing material passes two or even more drawing tools. Additionally there is even heat treatment in between these processes, what increases the cost dramatically.

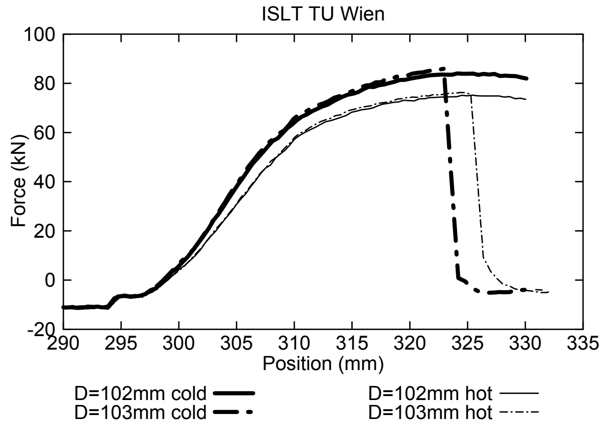

***Fig. 3:** limiting drawing ratio: cold blank holer vs. heated (80°C) blank holder*

Another possible solution to solve drawing problems is to control the flow of the sheet into the die by using a draw bead. There is also the possibility to influence the material flow by heating the workpiece or the tool. Cup drawing Tests with a diameter of 48mm have been made with a resistance wire heated blank holder [18]. X5CrNi18-10 with a thickness of 0.8mm has been used for the discs. The goal has been to find the largest possible diameter of the blank (limiting drawing ratio). **Fig. 3** shows the punch force for several tests. Results indicate that it is not possible to increase the maximum blank diameter by heating the whole disc.

So it is useful, in the example of cup drawing, to heat the outer diameter of the disc and cool the punch. Several authors used different temperature levels in the tool [2,3].

As it was shown before it is important to heat only areas of the tool or even better to heat the workpiece only. Lasers are well suited for a localized heat input. Several experiments demonstrate the feasibility of laser assisted forming processes [4,5,7,15]. There are other procedures where a laser treatment is combined with forming operations, e.g.: laser assisted metal spinning [20], which is a process that is very close to deep drawing. This process also allows the production of a hollow shape out of a flat sheet metal. The main difference is that this process can only produce symmetrical parts. Laser assisted bending [10,21] has the advantage that only a small area on the workpiece has to be heated since forming takes place only along a narrow line. Laser assisted roll forming [21] is well suited for laser assistance. The area where the forming operation takes place is very small and due to the character of the process, the material can be moved directly below the laser. Laser assisted wire drawing [12] is quite similar to laser assisted roll forming.

2 Experimental setup

For the experimental setup several laser sources, a manipulation system and a hydraulic deep drawing press have been used. The deep drawing tool was produced to build a cup with a diameter of 49mm and a sheet metal thickness of 0.8mm. It consists of a drawing die, a punch and a blank holder, made of hardened tool steel. To prevent heat flow out of the sheet metal, the blank holder and the drawing die are covered with an isolation layer. At the area near the punch there is a protecting ring (**Fig. 4**) from tool steel with a diameter of 55mm which prevents the isolation layer from breaking, since it cannot withstand the shear stress during the drawing operation.

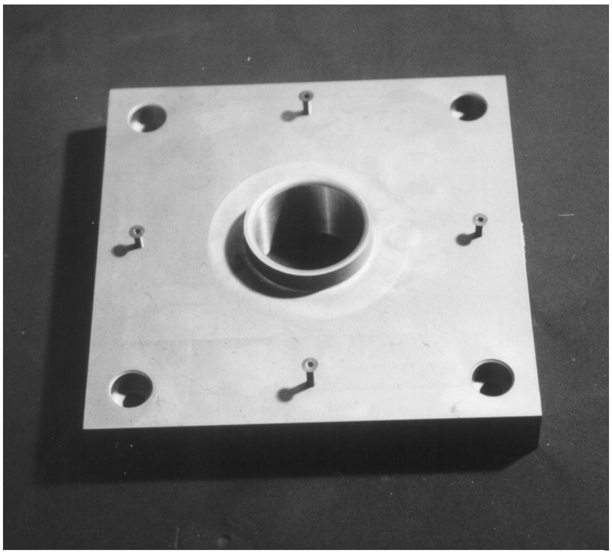

Fig. 4: *drawing die without isolation layer*

The hydraulic press (HP063 H/K-01) was built by Raster Zeulenroda and equipped with two hydraulic systems. One system for the ram of the press, the other for the die cushion. The drawing die is fixed on the ram of the press, the punch is mounted on the press table, and the blank holder is guided by pillars from the die cushion inside the press table. During the drawing operation the blank holder is pressed against the die and moved by the drawing die downwards. Maximum possible speed for the ram of the press is 10mm/sec and maximum force is 630kN. The die cushion can apply a maximum force of 160kN. The system is controlled by a “programmable logic control” (PLC). Three pressure gauges are connected with the hydraulic system (type: strain gauge bridge). The movement of the press ram is observed with a glass scale. Data is transformed by the PLC and sent via RS232 connection to a PC. The sampling time is about 40ms.

The Lasers are used in three different ways. First the diode laser Dilas DL01 with a maximum laser power of 1kW was fixed outside the press **(Fig. 5**) and the workpiece was moved below the laser. Another possibility is to put the sheet metal inside the press on the blank holder and move the laser beam inside the tool (**Fig. 6**). In this case the beam of a 3kW Trumpf Nd:YAG laser is transported by a fiber and reflected by a mirror on the sheet metal. A third possibility is the implementation of a fiber directly (**Fig. 8,9**) below the isolation layer inside the blank holder as well as mounting a 30W laserdiode (**Fig. 7**) made by Dilas into the tool.

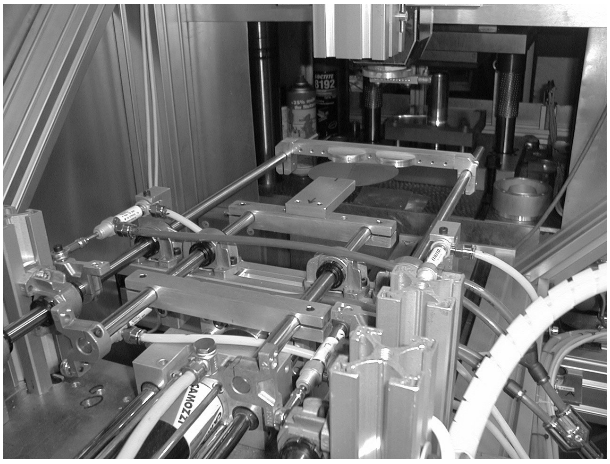

Fig. 5: *heating outside the press*

The manipulation system consists of a xy-table from Isel which was controlled by a G-Code compatible DOS Program. Maximum movement speed is 100mm/sec.

Blanks have been cut with a laser cutting system. Dross has been removed. During the various tests no lubrication has been used.

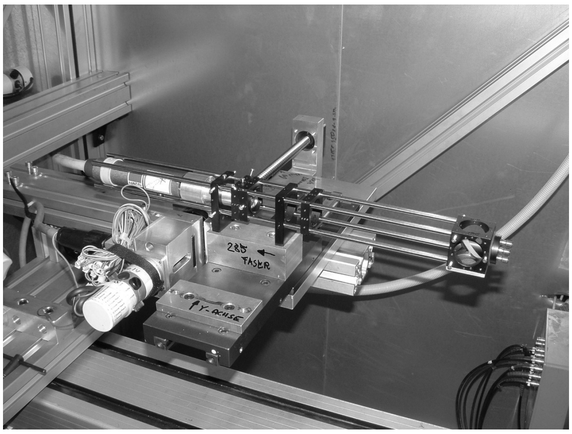

Fig. 6: *laserfinger [14]*

Fig. 7: *blank holder with laser diode [14]*

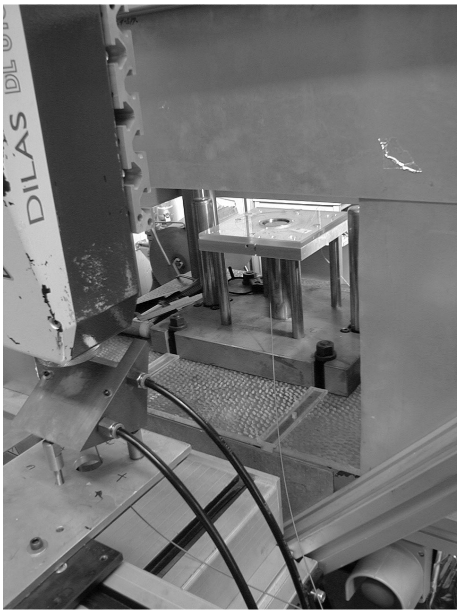

Fig. 8: *blank holder with fibre [14]*

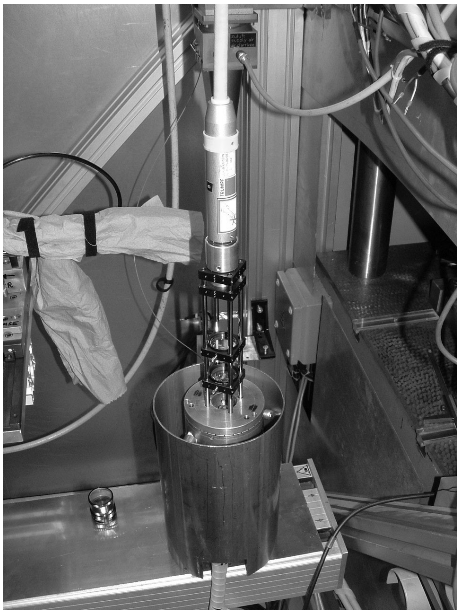

Fig. 9: *beam splitter [17]*

3 Results and discussion

Several test have been made with the equipment described before. First results have been achieved by heating outside the tool with the 1kW diode laser. The diameter of the used discs was 100mm. Test 189-003 was drawn without preheating while test 189-002 was with laser preheated. Parameters of the press were the same in both experiments. Maximum force of the ram was fixed at 100kN and the force of the cushion die was constant at 5kN. The irradiated area on the laser heated disc was about 15x10mm² with a power of 400W. Diameter of the preheated area was 85mm with a velocity of the sample of 50mm/s. Discs have been moved three times below the laser and afterwards into the press. As an isolation layer the glass ceramic "Macor" has been used. The non-preheated disc could not withstand the drawing forces and broke. Both samples can be seen in **Fig. 10** whereas the relevant forces are shown in **Fig. 11**.

Surface conditions (roughness) has been changed for the following experiments. The face of the disc close to the drawing die was brushed while the other side was bright finished. In this case the diameter of the disc was 90mm. Test 189 was performed with laser assistance, 230 without. As an isolation layer there was float glass used. The force diagram (**Fig. 12**) shows that the pressure of the blank holder was varied at a certain position in both tests. Necessary forces for the test with laser assistance are smaller than those without laser assistance. In this test the sheet metal was not pulled through the drawing die to prevent the isolation layer from breaking. In this case for the laser treatment again the Dilas DL01 was used to preheat the sheet metal outside of the press. The sheet metal was only moved once below the laser beam. The beam power was again 400W with a rectangular beam profile of 15 x 10mm².

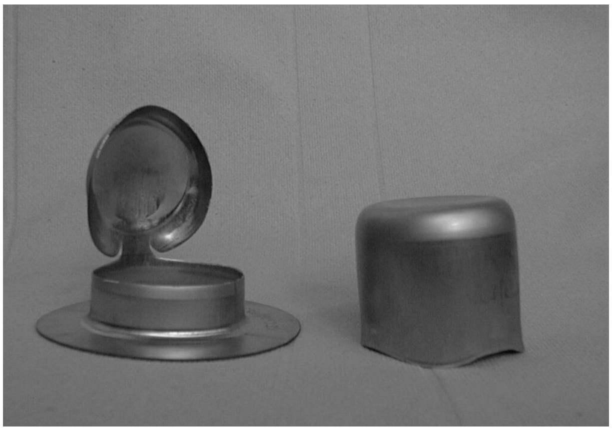

Fig. 10: *test 189-002 with laser assistance vs. 189-003 without laser assistance*

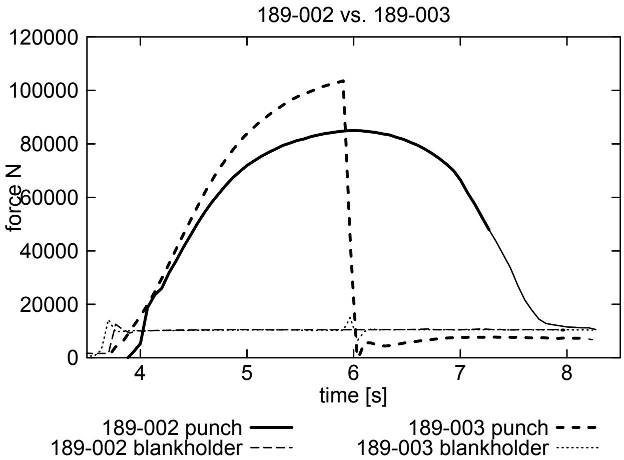

Fig. 11: *forces: 189-002 vs. 189-003*

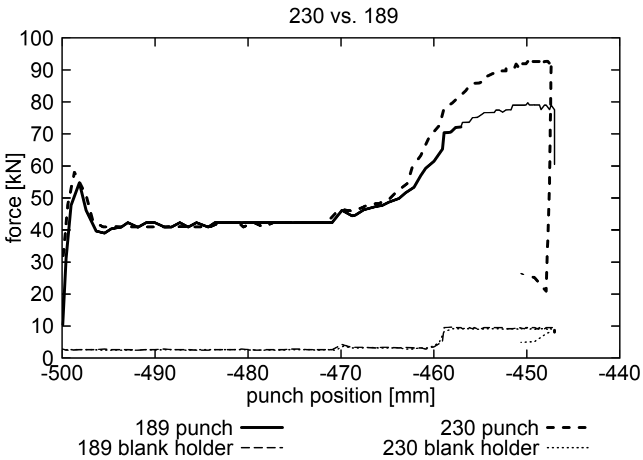

Fig. 12: *forces: 230 vs. 189*

There have been additional investigations concerning the diameter of the flange and the wall thickness after the drawing test. **Fig. 13** shows the radius of the flange. Measurements have been performed with a rotary stage and a dial gauge. The cup was fixed at the center and the flange radius has been measured every 5 degrees. It can be seen from diagram, the earing of the laser heated cup is smaller than the comparative test result.

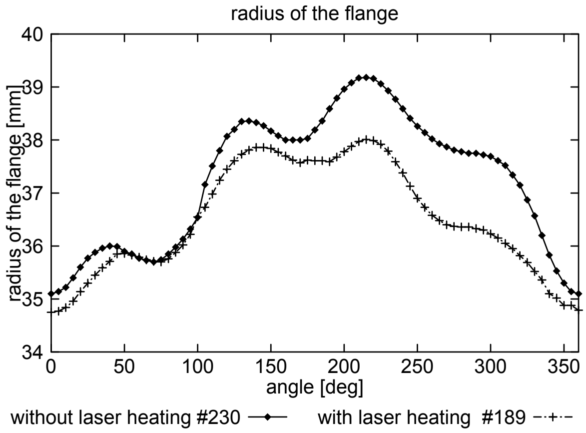

Fig. 13: *radius of the flange*

The samples had been cut by hand and the wall thickness had been measured starting at a distance of 8mm from the bottom of the cup. It was not possible to measure closer to the bottom because of the rounded edge of the cup. **Fig. 14** clearly indicates that the thickness of the laser heated material is more constant than that of the unheated one. Close to the bottom of the cup the thickness is even reduced from the initial thickness of the sheet metal of 0.8mm to 0.55mm.

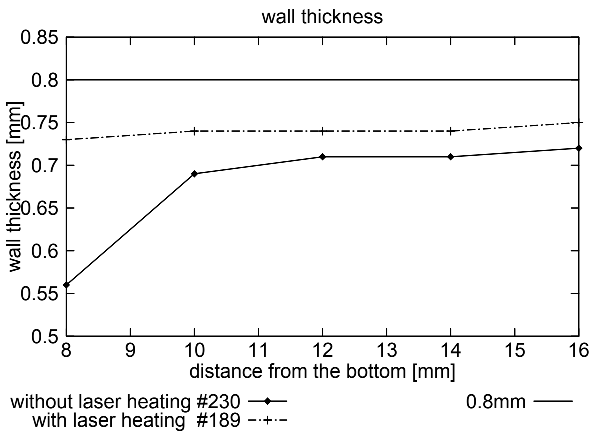

Fig. 14: *wall thickness*

An additional experiment is presented in the following text. Parameters of the test are almost the same compared to the previous one. However, one sample with laser assistance and the other without have been metallurgical examined. A section has been cut out of the cup with an watercooled circular saw. Afterwards the two pieces have been embedded, polished and finally the hardness has been measured. **Fig. 15** shows measured values of the laser heated and non heated samples. There has always been a measurement in the middle of the sheet metal, the so called "neutral area", near to the drawing die and to the blank holder. In **Fig. 16** and **17** the diagrams are shown for the unheated and the heated sample.

There have also been tests heating inside the tool using the laserfinger (**Fig. 18**). Results have been quite similar to the test with the preheating outside the press. More exciting test results have been achieved where the fibre was applied direct below the isolation layer inside the tool. The remaining flange was building a protrusion at the point where the fibre was applied. The contour plot of the flange (**Fig. 18**) was achieved by modifying the equidistant photographed digital picture with Imaq from National Instrument. Tests with the laser diode inside the blank holder lead also to a reduction of the needed drawing force.

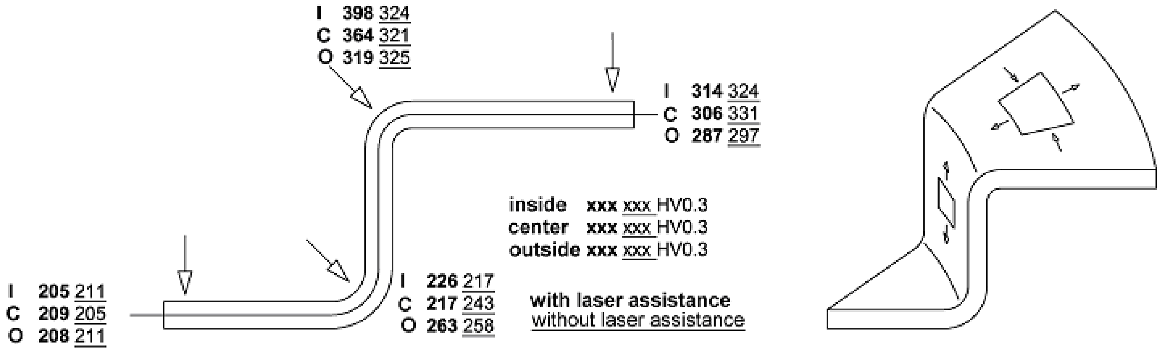

Fig. 15: *hardness measurement*

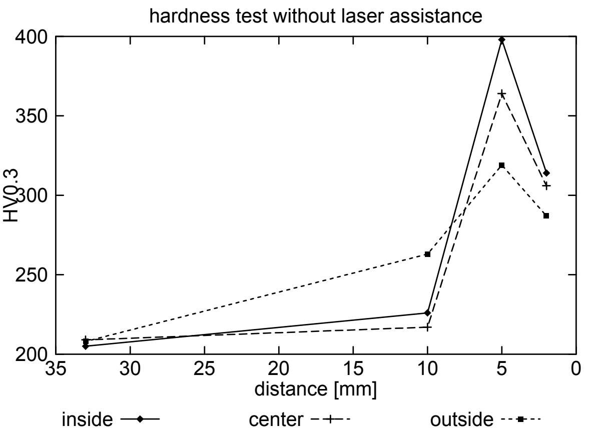

Fig. 16: *hardness test without laser assistance*

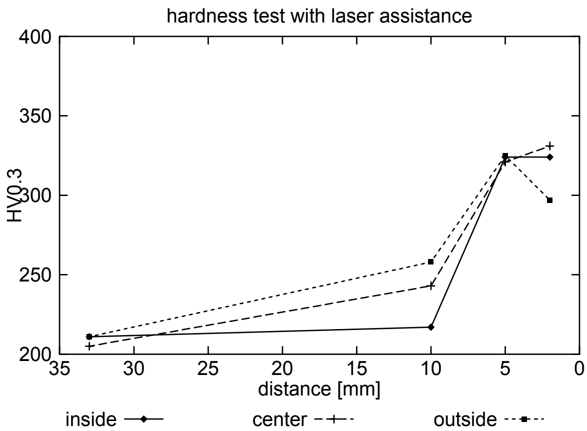

Fig. 17: *hardness test with laser assistance*

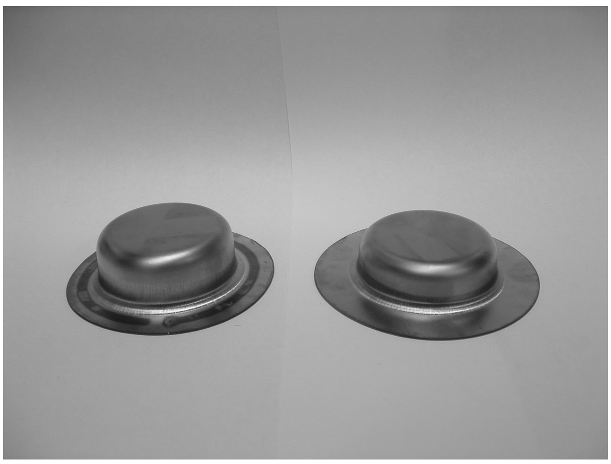

Fig. 18: *right side: drawn without laser assistance, left side: drawn with laserfinger*

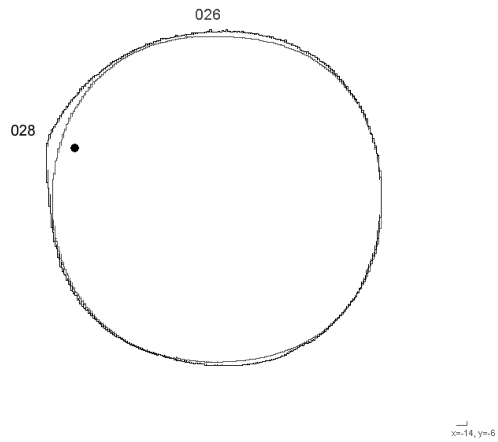

Fig. 19: *contour plot of flanges: sample 028 (with laser fibre a the point) and without laser assistance 026*

4 Conclusion

The results of these investigations show that the laser assisted forming process is able to enlarge the possibilities of deep drawing. Several possibilities for heating the workpiece have been examined. Heating with the diode laser outside the tool was an excellent choice for a feasibility study. It is very complicated to heat the workpiece outside the press and drop it in the correct place. The discs are bending because of the unequal heat distribution inside. By dropping the disc on the drawing tool it was nearly impossible to ensure that the disc is located in the right place. The laserfinger has the possibility to heat a workpiece while it is still inside the tool. So the disc can be put in the right place, heated by the laser beam and afterwards the forming operation takes place. This can be used for small production series or for prototyping a tool with laser assistance inside. First the correct position for the heat treatment can be tested by the laserfinger and afterwards laser diodes can be mounted inside the tool. It is worth mentioning that for the sheet thickness of 0.8mm laser diodes with an higher optical output than those used in the tests are necessary. (e.g.: MY-Series High Power Diode Lasers from Dilas are available with more then 100W).

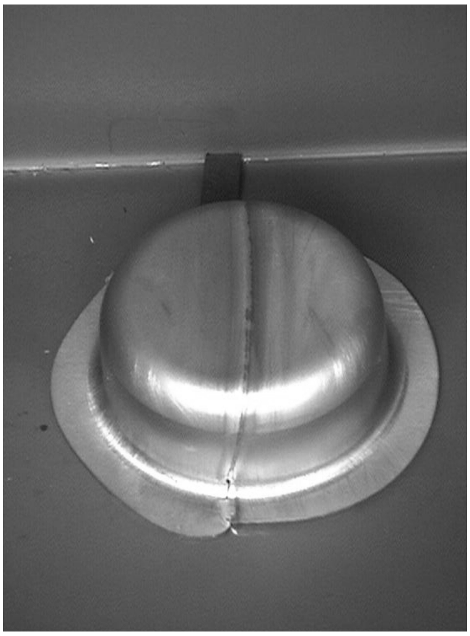

Fig. 20: *cup made from a tailored blank (FeP05-X5CrNi1810)*

The only possibility to use this process in industry is to include the laser source directly inside the tool. This will allow to use old forming presses together with the new technology of laser heating. Additionally this gives also the possibility to continue the laser treatment while the forming operation takes place.

The laser assisted deep drawing process has the possibility to change the material flow. Compared to the possibilities of the draw bead, the laser treatment is reducing the needed drawing forces and not increasing them. Another material flow problem, shown in **Fig. 20**, could also be solved with laser heat treatment. In this case two different materials have been joined together with a laser weld. Due to the different material properties the rest flange is not homogeneous. Heating in the area of X5CrNi18-10 could change the flow behaviour making a circular rest flange. Forming Problems resulting by the weld of tailored blanks could also be solved with laser heating.

A very important fact is that this kind of local heat treatment will only work if the sheet metal has a very low heat conduction. So the process will be suitable for stainless steel or titanium. Using materials with a good heat conduction has the disadvantage, that the temperature profile is rather flat and there will not be a big impact. It is also very important that there is a minimized heat transfer to the tool. So the classic tool steel is not a good choice. Isolation layers have to be put on the tool.

Finally, the additional costs of adding diode lasers, in comparison to the overall cost of the drawing tool itself, are very low. So it seems that there is a chance that this procedure will be realized an industrial environment in the future.

Acknowledgement

The work was mainly supported by the Austrian Government Bundesministerium für Verkehr Inovation und Technologie. Also Dr. Neukum of Dilas ,supported the project by letting ISLT two laser diodes.

References

[1] Doege, E.; Meyer-Nolkemper, H.; Saeed, I.: Fließkurven-Atlas metallischer Werkstoffe. Hanser Verlag München Wien, 1986
[2] Shipton W.T.R.: Hot deep drawing of titanium sheet. Materials Sience and Technologie, 1991,7:537-540
[3] Fischekov, N.: Tiefziehen von erwärmten Platinen reduziert Anzahl der Umformstufen. Maschinenmarkt , Würzburg 102 (1996) 51,1996, 20.-21.
[4] Schuöcker, D.; Schröder, K.: Laser assisted deep drawing. In: Laser Assisted Net Shape Engeneering, Proc of the LANE '97, Sept. 23.-26., 1997, Erlangen, Germany, 713-718
[5] Schuöcker, D.: Mathematical modelling of laser assisted deep drawing. In: Sheet Metal 99, Proc. Of SheMet'99, Sept. 27.-28. 1999, Erlangen, Germany 439-445
[6] Schuöcker, D.: Verfahren zur Materialbearbeitung durch Kombination von mechanischer Krafteinwirkung und Laserstrahlung Patent Nr.: AT 407 498 B. patent, Austrian Patent Office, August 2000, Vienna, Austria
[7] Schuöcker,D.: Mathematical modelling of laser assisted deep drawing. Journal of Materials Processing Technology, 115 (2001), 104 – 107
[8] Bielak, R.; Kratky, A.; Rohrhofer, K.; Schuöcker,D.: Anwendungen des Lasers zur Unterstützung von Umformprozessen unter besonderer Berücksichtigung des Tiefziehns. Report to Federal Ministry of Transport, Innovation and Technology, Vienna University of Technology, April 2001, Vienna, Austria
[9] Boden, H.: Laserunterstütztes Tiefziehen. diploma thesis, Vienna University of Technology, May 2001, Vienna, Austria
[10] Schuöcker, D.; Kilian, F.; Zeinar, C.; Kratky, A.: Laser Assisted Forming of Sheet Metals. In: Proceedings of Icaleo 2001, Oct. 15.-18., 2001, Jacksonville, USA
[11] Kratky, A.: Laserunterstütztes Tiefziehen, thesis, Vienna University of Technology, December 2001, Vienna, Austria
[12] Liedl, G.; Kratky, A; Schuöcker, D.: Laser assisted shaping of metallic sheets and wires – a promising new application of high power lasers. In: High Power Laser Ablation IV Vol. 4760, April 22.-26., 2002, Taos, USA, 633-644
[13] Mariño, A.: The Laser Assisted Deep Drawing Process. diploma thesis, Vienna University of Technology, June 2003
[14] Schuöcker, D.; Kratky, A.: Laserunterstütztes Tiefziehen mit Halbleiterlasern und Festkörperlasern Patent Nr.: 411.023. patent, Austrian Patent Office, July 2003, Vienna, Austria
[15] Schuöcker, D.; Kratky, A.; Bammer, F.; Liedl, G.; Holzinger, B.: Laser assisted forming. In: Proceedings Icaleo 2003, Oct. 13.-16., 2003, Jacksonvill, USA
[16] Kratky, A.; Liedl, G.; Schuöcker,D.: Laserunterstütztes Tiefziehen mit Diodenlaser. Report to Federal Ministry of Transport, Innovation and Technology, Vienna University of Technology, April 2004, Vienna, Austria

[17] Pérez Pérez, P.: Beam Splitter for Laser Assisted Deep Drawing Process. diploma thesis, Vienna University of Technology, July 2004, Vienna, Austria
[18] Arias Blanco, A.: Deep Drawing in Lubricated Stainless Steel Blanks. diploma thesis, Vienna University of Technology, July 2004, Vienna, Austria
[19] Erhardt, R.:Mikroumformen mit lokaler Bauteilerwärmung durch Laserstrahlung in transparenten Werkzeugen. http://www.ptu.tu-darmstadt.de/, PtU Darmstadt
[20] Wehrmeister, T.: Laserunterstütztes Metalldrücken schwer umformbarer Werkstoffe. http://www.ipt.fraunhofer.de/cms.php?id=1347, Fraunhofer IPT
[21] Pitz, M.: Laserunterstütztes Walzprofilieren. http://www.lft.uni-erlangen.de/,Lehrstuhl für Fertigungstechnologie Friedrich-Alexander-Universität Erlangen-Nürnberg